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Partial circulant diallel cross at the interpopulation level in the identification of elite lines and prediction of maize hybrids

Dialelo parcial circulante interpopulacional na identificação de linhagens elites e predição de híbridos de milho

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Highlights

PCDCI was efficient in identifying superior lines and hybrid combinations.
High correlation between yield observed and as predicted by the reduced model.
The *s*=4 number of combinations per line in the diallels was adequate.

Abstract

The Partial Circulant Diallel Cross at the Interpopulation Level (PCDCI) was proposed with the aim of better exploiting heterosis, by combining lines of different heterotic groups, and allowing the assessment of the combinatorial potential of a greater number of lines (*n*) which participate in *s* crosses, with a reduced number of evaluated hybrid combinations (*ns*), to estimate [*n*(*n*-*s*)] non-evaluated hybrids. The objectives of this study were to determine the potential of PCDCI to identify elite lines and superior combinations among the evaluated hybrids and to predict the performance of non-evaluated hybrids using a reduced model. Four PCDCI diallels were obtained involving six synthetics of maize, using groups of 20 S_5 lines per synthetic. Each line was combined with four lines of the contrasting group (*s*=4), in each diallel, resulting in 80 hybrid combinations per diallel, which were used to predict the performance of 320 other non-evaluated combinations. The 80 hybrid combinations and four commercial controls were evaluated for grain yield using a randomized block design with two replications, in two crops. Individual and combined analyses of variance were performed based on treatment means, with diallel analyses performed and genetic parameter effects estimated using the ordinary least squares method. The significant effects of

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general and specific combining ability and their interactions with the crops show that both additive and dominance effects were important for yield. The means of hybrids as estimated by the reduced models were highly correlated with the observed means, with correlation coefficients between 0.75 and 0.93. The use of PCDCI is efficient for predicting the hybrids not evaluated in the diallels and allows identifying elite lines for the production of hybrids.

Key words: Breeding. Combining ability. Diallel analysis. Elite lines. Mean prediction.

Resumo

A proposta do Cruzamento Dialelo Parcial Circulante Interpopulacional (CDPCI) foi desenvolvida com a finalidade de explorar melhor a heterose, ao combinar linhagens de diferentes grupos heteróticos, e viabilizar a avaliação do potencial combinatório de um maior número de linhagens (*n*), que participam em *s* cruzamentos, com um número reduzido de combinações híbridos avaliadas (*ns*), com a possibilidade de estimação de [*n*(*n*-*s*)] híbridos não avaliados. Os objetivos foram determinar o potencial do CDPCI para identificar linhagens elites e combinações superiores nos híbridos avaliados e predizer o desempenho dos híbridos não avaliados, por meio de um modelo reduzido. Foram obtidos quatro dialelos CDPCI's, envolvendo seis sintéticos de milho, empregando grupos de 20 linhagens S_5 por sintético, sendo cada linhagem combinada com quatro linhagens do grupo contrastante (*s*=4), em cada dialelo, dando um total de 80 combinações híbridas por dialelo, utilizadas para predição do desempenho de 320 outras combinações não avaliadas. As 80 combinações híbridas e quatro testemunhas comerciais foram avaliados para produtividade de grãos, utilizando o delineamento de blocos casualizados com duas repetições, em duas safras. As análises de variâncias individuais e conjuntas foram realizadas com base nas médias de tratamentos, sendo as análises dialélicas e estimativas de efeitos dos parâmetros genéticos realizadas pelo método dos quadrados mínimos ordinários. Os efeitos significativos de capacidade geral e específica de combinação e suas interações com safras, mostram que tanto os efeitos aditivos quanto de dominância foram importantes para a produtividade. Os modelos reduzidos para estimação de médias de híbridos tiveram elevada correlação com as médias observadas, com estimativas entre 0,75 e 0,93. O emprego do CDPCI's é eficiente para predição dos híbridos não avaliados nos dialelos e permite identificar linhagens elites para síntese de híbridos.

Palavras-chave: Capacidade de combinação. Melhoramento genético. Análise dialélica. Linhagens elites. Predição de médias.

Introduction

One of the greatest obstacles in maize breeding programs is the need to evaluate the performance of lines in crosses, since obtaining and evaluating all possible combinations is not feasible due to the large number of hybrids to be acquired and evaluated in the field. Accordingly, procedures are warranted that examine the combinatorial potential of a large number of inbred lines based on the results of a reduced sample of hybrid combinations and the estimated genetic parameters, making it possible to predict the performance of the other possible combinations not evaluated in the field (Hallauer et al., 2010; Reis et al., 2005). At present, the use of statistical models has significantly contributed to increasing efficiency in breeding. In this respect, genetic prediction models have provided a greater understanding of gene interactions, heritability, prediction of hybrid behavior, estimates of combining ability, among others, thereby reducing the time and costs of execution (Matias et al., 2018).

Throughout the history of breeding, several strategies have been adopted to maximize the efficiency of the process of evaluating genotypes in crosses. First, Davis (1927) proposed the top-crossing method, which consists of crossing *n* lines with a common tester to determine the value of each individual in hybrid combinations. In this method, it is important to select an adequate tester that contributes positively to the distinction of lines, classifying them regarding their combination potential and providing information that helps in the selection of superior lines and elimination of undesirable individuals (Miranda & Gorgulho, 2001; Hallauer et al., 2010). Even so, the possibility of eliminating lines with good combining ability is real due to the difficulty in identifying a tester with sufficient potential to cover large genetic diversities (Machado et al., 2008). Subsequently, the introduction of the general combining ability (GCA) and specific combining ability (SCA), concepts by Sprague and Tatum (1942), served as a basis for developing different diallel methodologies and assessing hybrid combinations (Jinks & Hayman, 1953; Griffing, 1956; Kempthorne & Curnow, 1961; Gardner & Eberhart, 1966; Eberhart & Gardner, 1966; Miranda & Geraldi, 1984; Miranda & Vencovsky, 1999). General combining ability is related to genes with predominantly additive effects, in addition to dominance effects and epistatic interactions of the additive × additive type, which result in better individual performance. Specific combining ability estimates refer to dominance effects and other epistatic interactions that are normally of small magnitude and can be neglected (Vencovsky & Barriga, 1992).

In full diallels with *n* parents, at least *n*(*n*-1)/2 hybrid combinations are obtained and evaluated. Increasing *n* leads to a significant increase in hybrid combinations, making the evaluation process unfeasible. To make the evaluation of a larger number of genotypes possible, Kempthorne and Curnow (1961) suggested the Circulant Partial Diallel model, where each of the *n* lines in the set is crossed to obtain only a part (*s*) of possible crosses with other lines from the same set, and from the total of *n*(*n*-1)/2 crosses, only (1/2)*ns* of this total will be obtained, where *s* ≥ 2. However, the scheme presented by Kempthorne and Curnow (1961) allows estimating variance components at the intrapopulation level, making it difficult to estimate variance components of individuals from divergent heterotic groups.

Through data simulation, Veiga et al. (2000) evaluated the efficiency of circulant diallels compared with full diallels to obtain GCA and SCA estimates. The authors concluded that: a) they have comparable efficiency for classifying parents as to GCA and SCA and the magnitude of the estimates of these parameters; b) the number of crosses of each parent (*s*) affects the estimates of GCA and SCA, requiring the definition of a minimum value of s to obtain adequate agreement in the estimates; and c) for lowheritability traits, it may be advantageous to increase the number of crosses per parent, up to a maximum of half the number of parents involved. Some studies demonstrate the ability of the circulant partial diallel method to estimate the GCA and SCA parameters, as well as predict the behavior of single, triple, and double hybrids (Gonçalves, 1987; A. C. V. Dantas, 1989; Sampaio, 1989; J. L. L. Dantas, 1992).

Based on the methodology proposed by Kempthorne and Curnow (1961), Miranda and Vencovsky (1999) developed an adaptation of the model for analyzing two distinct groups of lines at the interpopulation level, naming it the Partial Circulant Diallel Cross at the Interpopulation Level (PCDCI). These authors also presented a model of analysis of variance of lines and diagonals based on the scheme of circulant partial diallel crosses, which allows obtaining the estimate of variance for the GCA of the progenies of groups 1 and 2 (σ^2_{gI} and σ^2_{gII}) and the variance for SCA (σ^2_s), and, from these, the interpopulation additive and dominance variances.

In the PCDCI, each line *n* of a population is crossed with *s* lines of another population and *ns* hybrids of the diallel are evaluated in the field, which makes it possible to obtain useful parameters to estimate the performance of *n*(*n* - *s*) non-evaluated single hybrids, ultimately allowing an increase in the intensity of selection on the possible hybrid combinations (Miranda & Vencovsky, 1999). In this regard, it is important to determine the size *s* of combinations of each line, which will provide an adequate estimation of the GCA and SCA effects and indicate the value of each line in the production of hybrids. Different studies have shown high genetic correlations between observed and estimated means of hybrids when *s* values between three and five were used (Andrade, 1995; Araújo, 2000; Fuzatto, 2003).

Because the line tester of each population is a sample of lines from the opposite population, the combining ability and its effects truly reflect the potential of the lines to be used in crosses, which means the proposed procedure can provide reliable estimates of the means of hybrids to be predicted in the PCDCI. However, according to Mirada and Vencovsky (1999), more practical experiments would be necessary to better understand the properties and potential of the PCDCI in hybrid prediction and line selection. Therefore, the objectives of this study were to determine the potential of the Partial Circulant Diallel Cross at the Interpopulation Level (PCDCI) method to identify elite lines and predict single maize hybrid combinations.

Material and Methods

Six synthetics (ST_{01}, ST_{05}, ST_{07}, ST_{08}, ST_{09} and ST_{11}) developed by the Maize Breeding Program at the General Biology Department at the State University of Londrina (UEL) were used as sources for selfing and extraction of inbred lines. A sample of twenty S_5 lines of each of the six synthetics was selected considering individual performance (health, architecture, and yield) to be combined in a crossing field, in the PCDCI scheme, using four crosses (*s* = 4) between the synthetic I (ST_i) line and the synthetic J (ST_j) line, following Miranda and Vencovsky (1999).

In the 2017/17 crop, four crossing fields were implemented to obtain the PCDCIs of S_5 lines ($ST_{01} \times ST_{05}$; $ST_{07} \times ST_{11}$; $ST_{09} \times ST05$; and $ST_{11} \times ST_{08}$) at the Experimental Station of the Fazenda Escola farm at UEL, located in Londrina/PR, Brazil (23°20′ S, 51°33′ W, 576 m altitude).

Each of the four diallels was composed of 80 hybrid combinations and four conventional commercial controls (AG 9010, DKB 390, DOW 2B710, and P 30F98), which were evaluated in the 2017/18 and 2018/19 crops at the Experimental Station. The experiment was laid out in a completely randomized block design with two replications, in plots formed by 4.00 m rows spaced 0.90 m apart, totaling 3.60 m^2 of area and a density of 55,555 plants ha^{-1}.

The region is classified climatically (Köppen, 1936) as a Cfa type (subtropical mesothermal) with hot summers, infrequent frosts, and a tendency of rainfall concentration in the summer months, yet without a well-defined dry season.

The experiments were managed according to the technical recommendations for the maize crop. Grain yield was corrected to 13.5% moisture and an ideal stand of 20 plants per plot, following the covariance methodology modified by Miranda Filho (Vencovsky & Barriga, 1992), with values extrapolated to tons per hectare (t ha^{-1}).

Individual analyses of variance were performed based on the means of treatments and their effects were decomposed into diallel crosses (D), controls (C), and the D vs. C contrast. The diallel crosses were further decomposed into the general combining ability of the ST_i (GCA-ST_i) and ST_j (GCA-ST_j) synthetics and specific combining ability (SCA).

The diallel analyses were performed based on the mean of two replications of the hybrids, according to the model presented by Griffing (1956), adapted by Vencovsky and Barriga (1992):

$$Y_{ij} = m + g_i + g_j + s_{ij} + \bar{e}_{ij},$$

where Y_{ij} = mean of the hybrid between line i of the ST_i synthetic and line j of the ST_j synthetic; m = overall mean; g_i = general combining ability effect of line i of the ST_i synthetic; g_j = general combining ability effect of line j of the ST_j synthetic; s_{ij} = specific combining ability effect for the cross between lines i and j; and $\bar{e}_{ij}$ = error associated with the mean of the hybrids.

For analysis of variance of the PCDCIs and estimates of effects, the ordinary least squares method was applied using the matrix model below:

$$Y = X\beta + \varepsilon,$$

where Y = vector of the observed mean data (*ns* crosses); X = matrix of constants defined by the genetic model; β = vector of coefficients with values of 0 and 1 related to parameters m, g_i, g_j, and s_{ij}; and ε = vector representing the errors associated with the means. The sums of squares of analysis of variance were calculated for the full model and for the reduced models as per Miranda and Vencovsky (1999).

The estimated parameters were obtained directly using the solution of normal equations ($\hat{\beta} = (X'X)^{-1}) (X'Y)$) derived from the reduced model shown next:

$$Y_{ij} = m + g_i + g_j + \delta_{Iij}.$$

Because the X matrix is singular, the system of normal equations does not present a unique solution, requiring the adoption of the following restrictions:

$$\sum_i \hat{g}_i = \sum_j \hat{g}_j = 0,$$

where specific combining ability (s_{ij}) estimates are obtained as the differences between the observed means and the other parameters estimated with the reduced model ($s_{ij} = Y_{ij} - m - g_i - g_j$).

Thus, using GCA estimates (g_i and g_j), we obtained predictions of $n(n\text{-}s) = 320$ single-cross interpopulation hybrids (SIH_{ij}) not evaluated in the PCDCI by applying the expression below:

$$SIH_{ij} = m + g_i + g_j.$$

As an alternative, components of constant effects (τ_i and τ_j) were estimated, as described by Miranda and Vencovsky (1999), which also allowed estimating the means of the SIH_{ij} not evaluated in the PCDCI, using the following reduced model:

$$SIH_{ij} = m + \tau_i + \tau_j.$$

The observed means of the evaluated SIH_{ij} and their means as predicted by the reduced models were compared and correlations between them estimated to identify the efficiency of these reduced models in predicting the means of the SIH_{ij} not evaluated in the PCDCI.

Combined analyses of variance of the crops and their decomposition into the components of diallel analysis were carried out according to the methodology of Miranda and Vencovsky (1995), based on individual analyses and their combinations.

Results and Discussion

The experiments showed coefficients of variation between 11.2% and 15.3% (Table 1), indicating adequate experimental precision (Pimentel Gomes, 1985; Resende & Duarte, 2007).

There was a significant effect of crops on the experiments involving PCDCIs $ST_{07} \times ST_{11}$ and $ST_{09} \times ST_{05}$, demonstrating that the evaluated crops were under different soil-climatic conditions (Table 1).

Table 1

Mean squares based on the mean of the treatments and significance levels of combined analysis of variance involving the PCDCI with decomposition of the effects of crosses ($ST_i \times ST_j$) into general (GCA) and specific (SCA) combining abilities and estimates of variance for grain yield in t ha^{-1}. 2017/18 and 2018/19 crops

Source of Variation	DF	$ST_{01}\times ST_{05}$		$ST_{07}\times ST_{11}$		$ST_{09}\times ST_{05}$		$ST_{11}\times ST_{08}$	
Blocks/Crops	2	ns		ns		ns		ns	
Crops (C)	1	0.6643^{ns}		58.132*		14.016*		11.238^{ns}	
Treatments	83	2.9586^{ns}		1.5976^{ns}		2.4594*		3.2448*	
Controls (T)	3	1.5596^{ns}		4.3670*		2.2433^{ns}		7.3176*	
D *vs.* T	1	47.120*		4.3099^{ns}		9.5406*		5.4477^{ns}	
Diallel hybrids (D)	79	2.4527^{ns}		1.4581^{ns}		2.3780*		3.0623*	
GCA/Pop	38	4.1535*		2.1270*		4.0224*		4.6924*	
GCA-ST_i	19	4.2442*		1.5557*		6.1628*		3.3505*	
GCA-ST_j	19	4.0629*		2.6982*		1.8821*		6.0344*	
SCA	41	0.8763^{ns}		0.8381^{ns}		0.8539^{ns}		1.5514^{ns}	
Treatments × C	83	2.3323*		1.4551*		1.2935*		1.8480*	
T × C	3	1.2730*		1.2747^{ns}		0.4038^{ns}		0.7727^{ns}	
(T *vs.* D) × C	1	3.6705*		0.4443^{ns}		0.7679^{ns}		4.4656*	
D × C	79	2.3556*		1.4747*		1.3340*		1.8557*	
GCA/Pop × C	38	4.1700*		2.2109*		1.9587*		2.4292*	
GCA-ST_i × C	19	4.4319*		2.8393*		1.6031*		1.9440^{ns}	
GCA-ST_j × C	19	3.9082*		1.5825*		2.3143*		2.9143*	
SCA × S	41	0.6738*		0.7924^{ns}		0.7550*		1.3242*	
Error	166	0.4107		0.7082		0.3873		0.7978	
CV%		12.0		13.4		11.2		15.3	
Mean		7.53		8.89		7.84		8.26	
		Variance estimate							
Crop		17/18	18/19	17/18	18/19	17/18	18/19	17/18	18/19
V(g_{STi})[1]		0.123	2.533	0.149	0.265	0.453	0.866	0.250	0.624
V(g_{STj})[2]		0.155	1.642	0.147	0.412	0.275	0.569	0.158	0.983
V(diallel)[3]		0.484	3.623	0.289	1.325	0.580	2.444	0.716	2.751
V(s_{ij})[4]		0.206	-0.552	-0.007	0.649	-0.148	1.010	0.308	1.143
V(A_{12})[5]		0.254	5.230	0.308	0.546	0.936	1.787	0.516	1.289
V(A_{21})[6]		0.319	3.390	0.303	0.850	0.568	1.174	0.325	2.030
V(A_{12})$_{mean}$[7]		0.287	4.310	0.305	0.698	0.752	1.481	0.421	1.660
V(D_{12})[8]		0.220	-0.589	-0.007	0.692	-0.158	1.076	0.328	1.218

*, ns: significant at 5% and not significant by the F-test, respectively. [1]Variance of general combining ability of synthetic ST_i; [2]Variance of general combining ability of synthetic ST_j; [3]Variance of diallel hybrids; [4]Variance of specific combining ability; [5]Additive variance of synthetic ST_i; [6]Additive variance of synthetic ST_j; [7]Mean additive variance; [8]Dominance variance.

All combined analyses of variance revealed significant interaction effects between Treatment × Crop and Diallel hybrid × Crop for yield, revealing the viability of using these diallels in the study of the efficiency of PCDCI in breeding (Table 1). Since there was a significant Treatment × Crop effect in all experiments, its decomposition is the most important part to be presented and discussed, as the treatments performed differently between the crops with respect to grain yield.

The controls showed significant differences in the experiments evaluating the ST_{07} × ST_{11} and ST_{11} × ST_{08} diallels, meaning that they did not have uniform performance in these diallels. However, there was a Control × Crop interaction effect in the experiment evaluating the ST_{01} × ST_{05} diallel, demonstrating a different performance of these between the two crops (Table 1).

For the Diallel hybrids vs. Control contrast (D vs. T), there were significant differences in the experiments of the ST_{01} × ST_{05} and ST_{09} × ST_{05} diallels and the (D vs. C) × Crop interaction in the experiments of the ST_{01} × ST_{05} and ST_{11} × ST_{08} diallels (Table 1). In all cases, the overall mean of the controls exceeded the overall mean of the Diallel hybrids. Nonetheless, in all diallels evaluated in each crop, there were at least six experimental hybrids, which were clustered together with the best control (DKB390) by the Scott-Knott test (Table 2).

Table 2

Observed means of the diallel hybrids (Y_{ij}), means of the controls, and correlations between observed means (Y_{ij}) and means as estimated by the reduced models [$r(Y_{ij},Y_g)$ and $r(Y_{ij},Y_\tau)$], for grain yield in t ha^{-1}. 2017/18 and 2018/19 crops

Combination	ST_{01} × ST_{05}		ST_{07} × ST_{11}		ST_{09} × ST_{05}		ST_{11} × ST_{08}	
	17/18	18/19	17/18	18/19	17/18	18/19	17/18	18/19
$L_1 \times L_{1'}$	6.74^c	10.32^a	7.88^a	10.47^a	6.92^a	9.51^a	7.80^b	7.59^b
$L_1 \times L_{2'}$	6.60^c	10.31^a	5.14^a	9.41^b	5.81^a	10.08^a	9.11^a	11.52^a
$L_1 \times L_{3'}$	8.52^b	10.36^a	6.76^a	8.37^b	6.81^a	6.52^c	9.76^a	7.66^b
$L_1 \times L_{4'}$	6.76^c	10.18^a	8.26^a	11.24^a	7.06^a	8.40^b	8.09^a	10.58^a
$L_2 \times L_{2'}$	7.45^c	8.71^b	8.30^a	9.08^b	6.43^a	10.21^a	7.58^b	7.51^b
$L_2 \times L_{3'}$	7.55^b	7.42^b	9.34^a	8.39^b	7.22^a	8.45^b	5.94^b	8.81^a
$L_2 \times L_{4'}$	7.32^c	9.70^a	8.24^a	10.36^a	8.19^a	9.39^a	6.67^b	11.49^a
$L_2 \times L_{5'}$	8.30^b	8.67^b	8.66^a	11.44^a	7.52^a	9.48^a	6.09^b	8.20^a
$L_3 \times L_{3'}$	8.53^b	10.23^a	8.01^a	9.58^b	9.10^a	9.07^a	5.85^b	6.31^b
$L_3 \times L_{4'}$	6.94^c	8.52^b	8.73^a	9.67^b	7.72^a	8.99^a	8.72^a	8.00^b
$L_3 \times L_{5'}$	6.77^c	7.94^b	7.09^a	8.07^b	7.31^a	9.36^a	7.59^b	10.34^a
$L_3 \times L_{6'}$	6.83^c	8.26^b	8.33^a	9.09^b	9.38^a	8.28^b	6.62^b	8.91^a
$L_4 \times L_{4'}$	8.20^b	9.68^a	9.72^a	11.09^a	8.40^a	8.75^b	6.86^b	9.73^a
$L_4 \times L_{5'}$	7.22^c	7.30^b	8.15^a	6.98^b	8.44^a	9.19^a	8.83^a	9.20^a

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$L_4 \times L_{6'}$	7.20^{c}	8.89^{b}	7.97^{a}	7.30^{b}	7.92^{a}	8.82^{b}	8.58^{a}	7.97^{b}
$L_4 \times L_{7'}$	7.15^{c}	9.28^{a}	9.54^{a}	7.83^{b}	7.51^{a}	8.60^{b}	6.82^{b}	9.53^{a}
$L_5 \times L_{5'}$	6.95^{c}	6.25^{c}	9.08^{a}	9.20^{b}	7.82^{a}	8.33^{b}	7.71^{b}	6.29^{b}
$L_5 \times L_{6'}$	6.51^{c}	5.69^{c}	8.64^{a}	8.25^{b}	6.90^{a}	7.79^{b}	8.51^{a}	7.18^{b}
$L_5 \times L_{7'}$	8.00^{b}	8.38^{b}	7.36^{a}	10.01^{a}	8.17^{a}	8.54^{b}	7.83^{b}	4.13^{b}
$L_5 \times L_{8'}$	7.06^{c}	5.83^{c}	9.75^{a}	8.14^{b}	7.48^{a}	10.00^{a}	9.38^{a}	8.95^{a}
$L_6 \times L_{6'}$	5.71^{c}	6.04^{c}	7.25^{a}	8.04^{b}	8.74^{a}	9.20^{a}	8.30^{a}	9.34^{a}
$L_6 \times L_{7'}$	6.91^{c}	8.88^{b}	7.50^{a}	12.31^{a}	7.92^{a}	9.09^{a}	7.51^{b}	8.19^{a}
$L_6 \times L_{8'}$	8.05^{b}	4.70^{d}	8.69^{a}	9.69^{b}	7.69^{a}	9.16^{a}	8.80^{a}	10.2^{a}
$L_6 \times L_{9'}$	6.45^{c}	4.47^{d}	7.85^{a}	8.74^{b}	7.33^{a}	6.96^{c}	9.20^{a}	8.75^{a}
$L_7 \times L_{7'}$	8.71^{a}	8.85^{b}	8.55^{a}	11.44^{a}	7.93^{a}	9.64^{a}	8.41^{a}	8.59^{a}
$L_7 \times L_{8'}$	8.08^{b}	8.36^{b}	8.82^{a}	8.94^{b}	8.69^{a}	9.88^{a}	9.32^{a}	10.16^{a}
$L_7 \times L_{9'}$	7.14^{c}	7.57^{b}	7.76^{a}	8.23^{b}	7.07^{a}	7.83^{b}	9.73^{a}	9.73^{a}
$L_7 \times L_{10'}$	7.65^{b}	6.94^{c}	9.63^{a}	10.64^{a}	6.97^{a}	7.50^{b}	9.24^{a}	11.79^{a}
$L_8 \times L_{8'}$	7.86^{b}	8.46^{b}	8.75^{a}	10.68^{a}	8.86^{a}	7.86^{b}	9.72^{a}	10.2^{a}
$L_8 \times L_{9'}$	6.88^{c}	9.96^{a}	7.49^{a}	10.93^{a}	7.47^{a}	9.01^{a}	8.36^{a}	9.48^{a}
$L_8 \times L_{10'}$	6.59^{c}	8.14^{b}	7.90^{a}	13.00^{a}	7.87^{a}	8.40^{b}	9.80^{a}	8.80^{a}
$L_8 \times L_{11'}$	6.17^{c}	7.93^{b}	7.02^{a}	10.97^{a}	7.92^{a}	10.4^{a}	9.16^{a}	10.37^{a}
$L_9 \times L_{9'}$	7.65^{b}	9.44^{a}	6.43^{a}	9.29^{b}	7.44^{a}	8.07^{b}	5.45^{b}	9.90^{a}
$L_9 \times L_{10'}$	7.78^{b}	8.86^{b}	8.70^{a}	10.88^{a}	7.03^{a}	8.36^{b}	8.35^{a}	9.58^{a}
$L_9 \times L_{11'}$	6.70^{c}	8.19^{b}	7.05^{a}	7.27^{b}	7.05^{a}	7.58^{b}	9.16^{a}	11.26^{a}
$L_9 \times L_{12'}$	8.22^{b}	8.37^{b}	7.51^{a}	9.67^{b}	6.89^{a}	7.91^{b}	8.03^{a}	9.35^{a}
$L_{10} \times L_{10'}$	9.10^{a}	4.51^{d}	7.26^{a}	9.37^{b}	7.44^{a}	5.74^{c}	5.81^{b}	6.04^{b}
$L_{10} \times L_{11'}$	6.76^{c}	6.29^{c}	8.93^{a}	7.33^{b}	5.61^{a}	9.78^{a}	10.37^{a}	11.05^{a}
$L_{10} \times L_{12'}$	6.91^{c}	7.89^{b}	7.04^{a}	6.90^{b}	7.73^{a}	9.14^{a}	9.44^{a}	11.73^{a}
$L_{10} \times L_{13'}$	8.20^{b}	6.06^{c}	7.79^{a}	8.70^{b}	7.80^{a}	9.04^{a}	7.53^{b}	4.46^{b}
$L_{11} \times L_{11'}$	7.85^{b}	5.92^{c}	7.47^{a}	8.35^{b}	7.35^{a}	8.82^{b}	9.33^{a}	11.10^{a}
$L_{11} \times L_{12'}$	7.38^{c}	7.60^{b}	8.15^{a}	8.16^{b}	7.31^{a}	7.75^{b}	6.76^{b}	9.36^{a}
$L_{11} \times L_{13'}$	7.99^{b}	3.35^{d}	9.74^{a}	9.00^{b}	7.67^{a}	7.17^{c}	5.55^{b}	7.08^{b}
$L_{11} \times L_{14'}$	9.10^{a}	3.50^{d}	7.99^{a}	8.32^{b}	7.87^{a}	4.66^{d}	7.27^{b}	8.72^{a}
$L_{12} \times L_{12'}$	7.90^{b}	7.47^{b}	8.68^{a}	9.76^{b}	7.34^{a}	7.56^{b}	7.39^{b}	9.06^{a}
$L_{12} \times L_{13'}$	8.87^{a}	5.79^{c}	9.37^{a}	8.67^{b}	9.18^{a}	8.61^{b}	6.59^{b}	5.74^{b}
$L_{12} \times L_{14'}$	9.20^{a}	2.65^{d}	9.46^{a}	6.60^{b}	6.86^{a}	6.30^{c}	6.68^{b}	8.82^{a}
$L_{12} \times L_{15'}$	8.08^{b}	5.53^{c}	9.57^{a}	11.02^{a}	7.34^{a}	8.48^{b}	6.72^{b}	6.82^{b}
$L_{13} \times L_{13'}$	7.96^{b}	2.91^{d}	9.03^{a}	9.40^{b}	9.13^{a}	6.47^{c}	8.19^{a}	6.45^{b}
$L_{13} \times L_{14'}$	7.04^{c}	3.11^{d}	7.04^{a}	8.64^{b}	7.66^{a}	4.41^{d}	8.28^{a}	11.54^{a}
$L_{13} \times L_{15'}$	5.40^{c}	3.92^{d}	8.11^{a}	11.51^{a}	7.59^{a}	9.47^{a}	8.83^{a}	5.78^{b}
$L_{13} \times L_{16'}$	5.53^{c}	2.93^{d}	8.74^{a}	7.70^{b}	7.75^{a}	9.64^{a}	8.89^{a}	9.74^{a}
$L_{14} \times L_{14'}$	6.54^{c}	6.09^{c}	7.86^{a}	7.42^{b}	8.33^{a}	3.82^{d}	7.38^{b}	8.54^{a}

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continuation...

$L_{14} \times L_{15'}$	6.60^{c}	8.97^{b}	9.17^{a}	9.61^{b}	8.27^{a}	8.34^{b}	7.56^{b}	6.49^{b}
$L_{14} \times L_{16'}$	6.65^{c}	5.54^{c}	9.18^{a}	11.60^{a}	8.58^{a}	8.44^{b}	7.86^{b}	5.57^{b}
$L_{14} \times L_{17'}$	6.77^{c}	6.26^{c}	8.12^{a}	9.34^{b}	7.58^{a}	5.04^{d}	7.43^{b}	5.26^{b}
$L_{15} \times L_{15'}$	8.33^{b}	9.03^{b}	9.35^{a}	9.33^{b}	7.87^{a}	7.64^{b}	9.55^{a}	10.02^{a}
$L_{15} \times L_{16'}$	6.83^{c}	8.01^{b}	9.94^{a}	10.59^{a}	7.11^{a}	7.51^{b}	7.67^{b}	7.83^{b}
$L_{15} \times L_{17'}$	6.62^{c}	7.24^{b}	8.41^{a}	9.24^{b}	6.81^{a}	8.62^{b}	7.66^{b}	9.38^{a}
$L_{15} \times L_{18'}$	8.32^{b}	10.13^{a}	9.25^{a}	10.16^{a}	7.29^{a}	8.99^{a}	8.44^{a}	10.3^{a}
$L_{16} \times L_{16'}$	7.06^{c}	6.17^{c}	7.71^{a}	10.34^{a}	8.18^{a}	8.38^{b}	8.61^{a}	6.64^{b}
$L_{16} \times L_{17'}$	5.77^{c}	6.50^{c}	7.96^{a}	8.90^{b}	6.07^{a}	7.21^{c}	9.54^{a}	9.53^{a}
$L_{16} \times L_{18'}$	7.07^{c}	8.32^{b}	7.99^{a}	8.61^{b}	8.13^{a}	11.34^{a}	8.08^{a}	9.48^{a}
$L_{16} \times L_{19'}$	7.99^{b}	8.41^{b}	8.04^{a}	8.21^{b}	8.86^{a}	12.26^{a}	8.03^{a}	7.07^{b}
$L_{17} \times L_{17'}$	8.14^{b}	6.64^{c}	8.91^{a}	9.00^{b}	7.73^{a}	7.52^{b}	7.64^{b}	8.21^{a}
$L_{17} \times L_{18'}$	7.93^{b}	6.44^{c}	7.95^{a}	11.26^{a}	7.86^{a}	8.46^{b}	7.90^{b}	4.85^{b}
$L_{17} \times L_{19'}$	8.12^{b}	5.55^{c}	8.33^{a}	8.40^{b}	7.57^{a}	5.40^{d}	8.37^{a}	5.50^{b}
$L_{17} \times L_{20'}$	6.77^{c}	6.45^{c}	9.33^{a}	7.60^{b}	6.20^{a}	9.32^{a}	7.89^{b}	4.69^{b}
$L_{18} \times L_{18'}$	7.84^{b}	5.55^{c}	6.17^{a}	11.51^{a}	8.03^{a}	7.07^{c}	6.22^{b}	9.70^{a}
$L_{18} \times L_{19'}$	7.42^{c}	8.43^{b}	9.12^{a}	8.93^{b}	9.19^{a}	7.54^{b}	8.26^{a}	5.94^{b}
$L_{18} \times L_{20'}$	7.35^{c}	8.55^{b}	9.27^{a}	11.24^{a}	8.09^{a}	6.80^{c}	8.54^{a}	6.05^{b}
$L_{18} \times L_{1'}$	7.42^{c}	10.22^{a}	8.26^{a}	11.03^{a}	7.67^{a}	9.21^{a}	7.41^{b}	8.77^{a}
$L_{19} \times L_{19'}$	7.76^{b}	9.22^{b}	8.35^{a}	9.60^{b}	6.63^{a}	7.04^{c}	9.30^{a}	9.48^{a}
$L_{19} \times L_{20'}$	7.45^{c}	10.55^{a}	8.56^{a}	10.83^{a}	6.18^{a}	6.37^{c}	8.22^{a}	7.03^{b}
$L_{19} \times L_{1'}$	6.07^{c}	8.41^{b}	8.53^{a}	11.96^{a}	7.01^{a}	7.78^{b}	6.68^{b}	7.56^{b}
$L_{19} \times L_{2'}$	6.11^{c}	8.32^{b}	6.20^{a}	11.07^{a}	6.62^{a}	8.02^{b}	8.42^{a}	9.68^{a}
$L_{20} \times L_{20'}$	6.93^{c}	7.82^{b}	8.63^{a}	6.64^{b}	4.25^{a}	4.22^{d}	9.06^{a}	7.35^{b}
$L_{20} \times L_{1'}$	7.80^{b}	7.40^{b}	8.87^{a}	9.15^{b}	5.62^{a}	4.79^{d}	6.39^{b}	8.63^{a}
$L_{20} \times L_{2'}$	7.44^{c}	8.53^{b}	8.05^{a}	9.64^{b}	4.60^{a}	5.09^{d}	8.53^{a}	5.33^{b}
$L_{20} \times L_{3'}$	9.07^{a}	10.16^{a}	8.13^{a}	8.78^{b}	5.67^{a}	4.03^{d}	7.04^{b}	8.00^{b}
Controls								
AG9010	7.92^{b}	9.71^{a}	7.06^{a}	8.74^{b}	8.15^{a}	9.00^{a}	6.91^{b}	9.06^{a}
DKB390	9.44^{a}	12.23^{a}	9.98^{a}	13.00^{a}	10.24^{a}	10.67^{a}	9.51^{a}	12.92^{a}
D2B710	10.03^{a}	9.17^{b}	8.09^{a}	10.56^{a}	8.37^{a}	8.00^{b}	6.10^{b}	7.87^{b}
P30F98	9.32^{a}	11.38^{a}	10.00^{a}	9.39^{b}	8.92^{a}	7.74^{b}	9.81^{a}	10.20^{a}
Correlations between means								
$r(Y_{ij}.Y_{g})$	0.83	0.93	0.83	0.85	0.89	0.88	0.82	0.84
$r(Y_{ij}.Y_{\tau})$	0.79	0.87	0.78	0.79	0.84	0.80	0.75	0.78
$r(Y_{g},Y_{\tau})$	0.95	0.94	0.94	0.93	0.95	0.92	0.91	0.93

Means followed by the same letters belong to the same cluster of means by the Scott-Knott test at a 5% probability level.

As regards the GCA/pop × C interaction and its consequences, almost all effects were significant, with the exception of GCA-ST$_i$ × C in the ST$_{11}$ × ST$_{08}$ diallel experiment. For the SCA × C effects, there were also significant interactions between the specific combining abilities of the lines in the PCDCIs and the crops, except for the crosses between synthetics ST$_{07}$ × ST$_{11}$. Several studies have demonstrated that the GCA and SCA effects manifest an interaction with the environment (Beck et al., 1990; Araújo, 2000; Oliboni et al., 2013; Baretta et al., 2016). Addressing this situation, Nass et al. (2000) mentioned the need to select parents within specific environments to maximize hybrid performance.

The interpopulation variance estimates of the PCDCIs for V(g$_{STi}$) and V(g$_{STj}$) represent the significant variation of the effects related to GCA, which were relatively higher in the 2018/19 crop compared with the 2017/18 crop. Estimates of SCA variance [V(s$_{ij}$)] and dominance variance [V(D12)] were positive for at least one crop, indicating that dominance effects influenced yield in the PCDCI in at least one of the crops. However, the negative variance estimates are related to a deviation from the estimates and should be assumed to be equal to zero, which means dominance deviations were not important in these cases to contribute favorably to the increase in yield. Estimates of SCA are associated with dominance effects and other epistatic interactions that are sometimes of small magnitude and can be neglected (Vencovsky & Barriga, 1992).

Both crops showed positive mean interpopulation additive variance [V(A$_{12}$)$_{mean}$] estimates, with higher values found in the 2018/19 crop, which had the highest mean yields. The V(A$_{12}$)$_{mean}$ estimates for grain yield were between 0.287 (t ha^{-1})^2 (93.0 g plant^{-1})^2 and 4.310 (t ha^{-1})^2 (1396.5 g plant^{-1})^2 (Table 1). These results reveal that the synthetics used in this study have the potential for the extraction of lines with high performance *per se*, especially if we consider the results described by Andrade (1995) [40.85 (g plant^{-1})^2 for the selfing system and 72.25 (g plant^{-1})^2 for sib-crosses]; Souza (1983) [260.50 (g plant^{-1})^2 in half-sib progenies]; Nass et al. (2000) [99.20 (g plant^{-1})^2 and 134.60 (g plant^{-1})^2 in maize compounds]; Araújo (2000) [111.55, 165.3, and 63.09 (g plant^{-1})^2 for populations IAPAR 26 and BR 106 in three locations, using the PCDCI scheme]; and Fuzatto (2003) [38.44 (g plant^{-1})^2 to 120.56 (g plant^{-1})^2 for two populations].

Estimates of interpopulation dominance variance [V(D$_{12}$)] for yield were lower than the mean additive variance V(A$_{12}$)$_{mean}$, which shows that the additive part was more important than the dominance deviations (Table 1).

The best estimates of GCA (g$_i$) and constant effects (τ$_i$) of the ST$_i$ synthetic lines from different PCDCIs were 2.55 and 2.85 t ha^{-1}, respectively (Table 3). Similarly, the best g$_j$ and τ$_j$ estimates of the ST$_j$ synthetic lines from the different PCDCIs were 3.28 and 2.55 t ha^{-1}, respectively (Table 4). These results indicate that the different synthetics produced lines with a high frequency of favorable alleles and that they significantly contribute to the increase in yield in the crosses in which they participate. Considering the two crops and the estimates of GCA and constant effects, the lines of each synthetic that stood out are L$_9$ and L$_{15}$ of ST$_{01}$; L$_{15}$ of ST$_{07}$; L$_3$, L$_8$, and L$_{16}$ of ST$_{09}$; L$_{8'}$, L$_{11'}$, and L$_{12'}$ of ST$_{08}$; and L$_1$, L$_7$, and L$_{15}$ of ST$_{11}$, in combination with the ST$_{08}$ lines (Table 3). Likewise, L$_{1'}$, L$_{4'}$, L$_{10'}$, L$_{15'}$, and L$_{16'}$ of

ST_{11}, in combination with the ST_{07} lines; L_3, and L_7, of ST_{05}, in combination with the ST_{01} lines; and L_4, and L_5, of ST_{05}, in combination with the ST_{09} lines (Table 4).

Table 3
Estimates of mean (m), general combining ability (g_i), and constant effects (τ_i) of ST_i synthetic lines in the different PCDCIs ($ST_i \times ST_j$) for grain yield in t ha^{-1}. 2017/18 and 2018/19 crops

Dialell	$ST_{01} \times ST_{05}$		$ST_{07} \times ST_{11}$		$ST_{09} \times ST_{05}$		$ST_{11} \times ST_{08}$	
Crop	17/18	18/19	17/18	18/19	17/18	18/19	17/18	18/19
m	7.38	7.44	8.27	9.43	7.48	8.05	8.00	8.40
g_1	-0.30	1.67	-1.26	-0.23	-0.99	-0.72	1.35	1.88
τ_1	-0.23	2.85	-1.27	0.45	-0.83	0.58	0.69	0.94
g_2	0.06	0.05	0.70	-0.24	-0.41	0.46	-0.98	1.10
τ_2	0.27	1.18	0.36	0.39	-0.14	1.34	-1.43	0.60
g_3	-0.35	0.14	-0.01	-0.78	0.29	0.59	-0.17	0.09
τ_3	-0.12	1.30	-0.23	-0.32	0.89	0.88	-0.81	-0.01
g_4	-0.08	-0.04	0.91	-2.01	0.00	0.51	0.49	0.54
τ_4	0.06	1.34	0.57	-1.13	0.58	0.79	-0.23	0.71
g_5	-0.57	-1.93	0.72	-0.77	-0.47	0.48	0.85	-2.26
τ_5	-0.25	-0.90	0.43	-0.53	0.11	0.62	0.35	-1.76
g_6	-0.84	-2.42	-0.14	0.36	0.06	0.87	0.90	0.01
τ_6	-0.60	-1.42	-0.45	0.27	0.44	0.55	0.45	0.72
g_7	0.13	-0.12	0.47	0.06	0.07	1.42	1.46	0.80
τ_7	0.51	0.49	0.42	0.39	0.18	0.66	1.17	1.66
g_8	-0.52	1.30	-0.49	2.36	0.71	1.65	0.69	-0.51
τ_8	-0.51	1.18	-0.48	1.97	0.55	0.87	1.26	1.31
g_9	0.52	1.19	-0.61	0.24	-0.03	0.95	-1.01	-0.30
τ_9	0.21	1.27	-0.85	-0.15	-0.38	-0.07	-0.25	1.63
g_{10}	0.51	-0.88	-0.62	-1.15	-0.29	1.33	-0.51	-1.31
τ_{10}	0.36	-1.25	-0.52	-1.35	-0.34	0.38	0.29	-0.08
g_{11}	0.79	-1.50	0.18	-0.07	0.11	0.44	-1.62	-0.80
τ_{11}	0.70	-2.35	0.06	-0.97	0.07	-0.95	-0.78	0.67
g_{12}	1.08	-1.18	0.96	-0.08	0.13	1.02	-1.64	-1.24
τ_{12}	1.13	-2.08	1.00	-0.41	0.20	-0.31	-1.16	-0.79
g_{13}	-0.93	-2.49	-0.32	-0.10	0.49	0.52	0.28	0.38
τ_{13}	-0.90	-4.23	-0.04	-0.11	0.55	-0.55	0.54	-0.02
g_{14}	-0.50	1.12	0.22	0.11	1.10	-0.61	-0.78	-1.98
τ_{14}	-0.74	-0.73	0.31	0.07	0.71	-1.64	-0.44	-1.93

continue...

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g_{15}	0.45	2.55	0.86	-0.13	0.15	-0.06	0.18	1.44
τ_{15}	0.14	1.16	0.96	0.40	-0.21	0.14	0.33	0.98
g_{16}	-0.28	1.19	-0.51	-0.33	0.59	1.36	0.48	0.49
τ_{16}	-0.41	-0.09	-0.35	-0.41	0.33	1.75	0.56	-0.22
g_{17}	0.47	-0.62	0.10	0.17	0.31	-1.02	-0.19	-1.51
τ_{17}	0.36	-1.17	0.36	-0.36	-0.14	-0.37	-0.05	-2.59
g_{18}	0.18	0.65	-0.53	1.56	0.96	-1.82	-0.16	0.70
τ_{18}	0.13	0.74	-0.07	1.25	0.76	-0.39	-0.39	-0.79
g_{19}	-0.31	1.20	-0.66	1.85	-0.57	-2.40	0.22	1.81
τ_{19}	-0.54	1.68	-0.36	1.44	-0.87	-0.74	0.15	0.04
g_{20}	0.49	0.12	0.02	-0.80	-2.22	-4.96	0.16	0.67
τ_{20}	0.43	1.04	0.15	-0.87	-2.45	-3.52	-0.25	-1.07
$r(g_i, \tau_i)$	0.93	0.79	0.93	0.89	0.90	0.78	0.81	0.56

Table 4

Estimates of diallel mean (m), general combining ability (g_j), and constant effects (τ_j) of ST_j synthetic lines in different PCDCIs ($ST_i \times ST_j$) for grain yield in t ha^{-1}. 2017/18 and 2018/19 crops

Dialell	$ST_{01} \times ST_{05}$		$ST_{07} \times ST_{11}$		$ST_{09} \times ST_{05}$		$ST_{11} \times ST_{08}$	
Crop	17/18	18/19	17/18	18/19	17/18	18/19	17/18	18/19
m	7.38	7.44	8.27	9.43	7.48	8.05	8.00	8.40
$g_{1'}$	-0.39	0.73	0.72	0.63	0.03	2.25	-1.32	-1.53
$\tau_{1'}$	-0.38	1.64	0.11	1.23	-0.68	-0.22	-0.93	-0.26
$g_{2'}$	-0.47	0.77	-1.05	0.23	-0.57	2.21	0.22	-1.25
$\tau_{2'}$	-0.48	1.52	-1.35	0.38	-1.62	0.30	0.41	0.11
$g_{3'}$	1.06	1.61	-0.08	-0.13	0.55	0.12	-0.94	-1.64
$\tau_{3'}$	1.03	2.10	-0.21	-0.65	-0.28	-1.03	-0.85	-0.70
$g_{4'}$	0.09	1.62	0.38	1.98	0.64	0.63	-0.59	0.65
$\tau_{4'}$	-0.08	2.08	0.46	1.16	0.36	0.84	-0.42	1.55
$g_{5'}$	0.16	0.54	-0.61	0.45	0.43	0.53	-0.49	0.24
$\tau_{5'}$	-0.07	0.10	-0.03	-0.50	0.29	1.04	-0.45	0.11
$g_{6'}$	-0.36	0.84	-0.60	-0.46	0.78	-0.14	-0.52	0.36
$\tau_{6'}$	-0.82	-0.22	-0.23	-1.26	0.75	0.47	0.00	-0.05
$g_{7'}$	0.65	2.53	-0.53	1.56	0.48	0.10	-1.28	-0.56
$\tau_{7'}$	0.31	1.41	-0.04	0.97	0.40	0.92	-0.36	-0.79
$g_{8'}$	0.83	0.19	0.59	-0.56	0.60	0.07	0.33	1.97
$\tau_{8'}$	0.38	-0.60	0.73	-0.06	0.70	1.17	1.30	1.48

continue...

continuation...

$g_{9'}$	-0.17	0.43	-0.70	-0.88	-0.36	-1.30	-0.33	1.06
$\tau_{9'}$	-0.35	0.42	-0.89	-0.13	-0.16	-0.08	0.18	1.07
$g_{10'}$	0.24	-0.70	0.41	1.17	-0.27	-1.89	0.14	0.98
$\tau_{10'}$	0.40	-0.33	0.10	1.55	-0.16	-0.55	0.30	0.65
$g_{11'}$	-0.84	-0.39	-0.27	-1.29	-0.63	0.01	2.12	3.28
$\tau_{11'}$	-0.51	-0.36	-0.66	-0.95	-0.50	1.10	1.50	2.55
$g_{12'}$	-0.50	0.98	-0.41	-0.54	-0.15	-0.89	1.10	2.39
$\tau_{12'}$	0.22	0.39	-0.43	-0.80	-0.17	0.04	-0.10	1.48
$g_{13'}$	0.51	-1.40	0.66	-0.13	0.85	-1.05	-0.17	-1.73
$\tau_{13'}$	0.87	-2.91	0.71	-0.48	0.96	-0.23	-1.04	-2.47
$g_{14'}$	0.48	-2.59	-0.44	-1.64	-0.26	-3.59	0.34	1.92
$\tau_{14'}$	0.59	-3.61	-0.18	-1.68	0.20	-3.25	-0.60	1.01
$g_{15'}$	-0.31	-0.58	0.35	0.99	-0.18	0.22	0.65	-0.77
$\tau_{15'}$	-0.28	-0.58	0.78	0.94	0.29	0.43	0.16	-1.12
$g_{16'}$	-0.55	-2.38	0.56	0.74	-0.16	0.14	0.22	-1.04
$\tau_{16'}$	-0.87	-1.78	0.62	0.63	0.43	0.44	0.26	-0.96
$g_{17'}$	-0.59	-1.84	-0.09	-0.26	-0.97	-0.87	0.14	0.09
$\tau_{17'}$	-0.56	-0.78	0.08	-0.31	-0.43	-0.95	0.06	-0.30
$g_{18'}$	0.20	-0.78	-0.42	0.64	-0.16	1.30	-0.42	-0.10
$\tau_{18'}$	0.41	0.17	-0.43	0.96	0.34	0.92	-0.34	0.18
$g_{19'}$	0.43	-0.15	0.59	-1.45	0.26	0.98	0.40	-1.77
$\tau_{19'}$	0.44	0.46	0.19	-0.64	0.58	0.01	0.49	-1.40
$g_{20'}$	-0.47	0.56	0.94	-1.04	-0.92	1.18	0.42	-2.54
$\tau_{20'}$	-0.26	0.90	0.67	-0.35	-1.30	-1.37	0.43	-2.12
$r(g_j, \tau_j)$	0.85	0.86	0.84	0.84	0.73	0.54	0.71	0.90

The predictive power of the reduced models ($Y_g = m + g_i + g_j$ and $Y_\tau = m+ \tau_i + \tau_j$) for estimating the yield of the single hybrids not evaluated in the diallel [*n*(*n*-*s*)=320 hybrids] was determined through Pearson correlations (r) between the observed means of the evaluated hybrids and the means of these same hybrids as estimated by the reduced models (Table 4). The correlations between the g_j and τ_j estimates were positive and ranged from 0.54 to 0.90, revealing a close association between these estimates (Tables 3 and 4). Correlations were also positive and high between the means predicted by the reduced models using the GCA estimates (g_i and g_j) and the constant effects (τ_i and τ_j), ranging from 0.91 to 0.95 (Table 2). However, there were greater positive correlations between the observed and estimated means for $r(Y_{ij}, Y_g)$ than for $r(Y_{ij}, Y_\tau)$ (Table 2), regardless of whether or not there were significant effects of SCA and SCA × Crop (Table 1). These results denote that the reduced model that employs the

GCA estimates is better than the model that uses constant effects. These findings also show that the use of *s* = 4 allowed a good prediction of the means of the non-evaluated single hybrids, corroborating the data presented by Miranda and Vencovsky (1999), Araújo (2000), and Fuzatto (2003).

In the ST_{01} × ST_{05} diallel, only one experimental hybrid with superior performance for both crops was grouped together with the best commercial control by the Scott-Knott test. However, in the ST_{07} × ST_{11}, ST_{09} × ST_{05}, and ST_{11} × ST_{08} diallels, 26, 27 and 28 experimental hybrids were grouped together with the best control, respectively, with superior performance in both crops (Table 2). These results demonstrate the productive potential of the lines used for the development of hybrids with potential for commercial exploitation.

With a view to selecting non-evaluated hybrid combinations, means were predicted based on the reduced model that employs GCA, and the 20% best hybrids of each crop were identified. Subsequently, those that performed best in both crops were selected. As a result of this selection, the following hybrids stood out: $HS_{02.07'}$, $HS_{09.03'}$, $HS_{09.07'}$, $HS_{15.03'}$, $HS_{15.07'}$, $HS_{15.08'}$, $HS_{15.10'}$, $HS_{15.19'}$, $HS_{16.03'}$, $HS_{18.03'}$, $HS_{18.07'}$, $HS_{19.03'}$ and $HS_{20.07'}$ for the ST_{01} × ST_{05} dialell; $HS_{07.04'}$, $HS_{12.04'}$, and $HS_{15.04'}$ for the ST_{07} × ST_{11} dialell; $HS_{08.03'}$, $HS_{08.04'}$, $HS_{08.05'}$, $HS_{08.07'}$, $HS_{08.19'}$, $HS_{12.14'}$, $HS_{14.01'}$, $HS_{16.04'}$, and $HS_{16.05'}$ for the ST_{09} × ST_{05} dialell; and $HS_{01.08'}$, $HS_{01.10'}$, $HS_{01.11'}$, $HS_{01.12'}$, $HS_{01.14'}$, $HS_{01.17'}$, $HS_{02.11'}$, $HS_{03.11'}$, $HS_{04.11'}$, $HS_{04.12'}$, $HS_{06.11'}$, $HS_{06.12'}$, $HS_{06.14'}$, $HS_{07.11'}$, $HS_{07.12'}$, $HS_{07.14'}$, $HS_{08.12'}$, $HS_{13.11'}$, $HS_{13.12'}$, $HS_{15.11'}$, $HS_{15.12'}$, $HS_{16.11'}$, $HS_{16.12'}$, $HS_{17.11'}$, $HS_{18.11'}$, $HS_{19.11'}$, $HS_{19.12'}$, $HS_{20.11'}$ and $HS_{20.12'}$ for the ST_{11} ×ST_{08} dialell.

In general terms, in the diallel between the ST_{01} × ST_{05} synthetics, 18 hybrids were selected, consisting of five tested hybrids and 13 predicted hybrids; for the ST_{07} × ST_{11} diallel cross, four tested hybrids and three predicted hybrids stood out, totaling seven hybrids; in the diallel crosses between the ST_{09} × ST_{05} synthetics, 11 hybrids were superior, two of which two were tested and nine predicted; and in the ST_{11} × ST_{08} diallel, nine tested hybrids and 29 predicted hybrids were highlighted, totaling 38 selected hybrids.

Conclusions

The method of Circulant Partial Diallel Cross at the Interpopulation Level is efficient to identify elite lines with potential for use as testers in the breeding program.

Means predicted using the reduced model through GCA estimates are highly correlated with the means of the evaluated hybrids, making this model efficient to estimate the mean of the non-evaluated hybrids, even in cases with significant SCA effects.

The use of an *s* = 4 is suitable for obtaining GCA and SCA estimates, which in turn allow for making adequate predictions of means.

The experimental hybrids with the best yield estimates for the ST_{01} × ST_{05} diallel were combinations $HS_{15.03'}$, $HS_{15.07'}$, and $HS_{09.07'}$; for the ST_{07} × ST_{11} diallel, hybrids $HS_{12.04'}$, $HS_{04.04'}$ and $HS_{15.04'}$; for the ST_{09} × ST_{05} diallel, experimental hybrids $HS_{16.19'}$ and $HS_{08.04'}$; and for the ST_{11} × ST_{08} diallel, hybrids $HS_{01.12'}$, $HS_{01.11'}$ and $HS_{04.11'}$.

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